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(54) Title: IMAGE SENSOR BULK CURRENT FEEDBACK FOR CONTROLLING ILLUMINATION

(57) **Abstract:** An embodiment of the invention is directed to a method for controlling illumination of a scene being captured by an image sensor, responsive to a signal that represents a bulk current. The image sensor has a bulk region on which a number of photosites are disposed. Light reflected from the scene and incident upon the image sensor contributes to the bulk current from the bulk region.

IMAGE SENSOR BULK CURRENT FEEDBACK FOR CONTROLLING ILLUMINATION

Field of the Invention

This invention is generally related to solid state cameras and more particularly to techniques for controlling the illumination of a scene being captured by the camera.

Background Information

Solid state cameras are becoming increasingly popular as the price of imaging electronics including the solid state image sensor is being reduced through design and manufacturing improvements. An essential part of taking good quality pictures under low light conditions using a solid state camera is to properly illuminate the scene being captured. Otherwise, the picture may become either too dark (not enough "flash") or too bright, i.e. too much flash. In still image cameras, the flash or "strobe" is typically controlled using a dedicated photoelectric circuit. The illumination of the scene is detected by the photoelectric circuit and when a sufficient level has been reached, the strobe is quenched. While such a technique may achieve the proper illumination for taking good quality pictures, it can add significantly to the manufacturing cost of the camera. For instance, the separate, dedicated photoelectric sensor circuit must be manufactured and incorporated into the camera together with its own optics, separate from the camera's image sensor and imaging optics. In addition, the response of the dedicated circuit and associated optics needs to be calibrated in relation to the output from the image sensor and imaging optics, so that an accurate determination of the amount of strobe light required to illuminate the scene being captured by the image sensor can be made.

SUMMARY

An embodiment of the invention is directed to an improved method for controlling illumination of a scene. Light reflected from the scene is allowed to be incident upon an image sensor. The image sensor has a bulk region. A number of photosites of the image sensor are disposed on a surface of the bulk region. A first signal representative of a bulk current from the bulk region is provided. Illumination of the scene is controlled responsive to the first signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements and in which:

Fig. 1 illustrates a block diagram of an image sensor that can be configured according to an embodiment of the invention.

Fig. 2 illustrates a side view of the image sensor, through a cross section, and a circuit for controlling illumination according to an embodiment of the invention.

Fig. 3 illustrates a side view of the image sensor and a circuit for controlling illumination according to another embodiment of the invention.

Fig. 4 shows a schematic of a circuit for controlling illumination.

Figs. 5 and 6 illustrate signal timing for controlling illumination and capturing a scene.

Fig. 7 shows a block diagram of an imaging system, such as a solid state camera, configured according to an embodiment of the invention.

DETAILED DESCRIPTION

The various embodiments of the invention provide improved techniques for controlling the illumination of a scene that is being captured by a solid state image sensor, such that the manufacturing cost of the imaging system that contains the solid state image sensor may be reduced without degrading the quality of pictures taken under low light conditions. The conventional, dedicated photoelectric circuit and associated optics used for metering light to control the strobe are eliminated. Instead, the image sensor and imaging optics are used to measure the light reflected from the scene, through the same optical train that is responsible for producing pictures of the scene. This is accomplished by using a feedback system that controls the light source, e.g. the strobe, based on a signal that is representative of a bulk current. This bulk current is due, for the most part, to photogenerated charge in the image sensor caused by the incident light reflected from the scene being captured. This photogenerated charge flows through a bulk terminal of the image sensor. Using a current measurement circuit for detecting the bulk current, and controlling illumination of the scene based upon the sensed bulk current, the embodiments of the invention provide an excellent opportunity for further

reducing the cost of solid state cameras by eliminating the conventional, dedicated photoelectric circuit and its associated optics.

Referring to **Fig. 1**, a solid state semiconductor image sensor 104 is illustrated. The image sensor 104 may be of a conventional type manufactured by a metal oxide semiconductor (MOS) process, or it may alternatively be of a charge coupled device (CCD) variety. In general, it will be apparent from the following description that the invention in its various embodiments is not limited to any particular type of image sensor. The image sensor 104 includes an array of photosites 108, each to provide an electrical signal in proportion to the sensed, incident light such that together, the photosites can electrically capture the scene whose image is incident upon the array. Each photosite 108 includes a photodetector (e.g. such as a photodiode, a photogate, or other type of photodetector), active circuitry such as an amplifier, and a readout circuit that enables accurate and reliable sampling of signals representing the sensed incident light. The signals representing the incident light appear on bitlines, where each bitline is connected to a column of photosites for the example shown in **Fig. 1**. Each row of photosites is connected to a common reset line which is used to prepare each connected photosite at the start of an exposure interval to detect the incident light. The signal representing the sensed incident light is placed on the bitlines by asserting the row select signals, allowing the signals on the bitlines to be sampled on a row by row basis. One of ordinary skill in the art will recognize that the exemplary architecture for the image sensor 104 described above and shown in **Fig. 1** is not the only architecture which can benefit from the invention's techniques for controlling illumination. The image sensor 104 shown in **Fig. 1** is merely a convenient example provided to more easily describe the various embodiments of the invention.

Turning now to **Fig. 2**, this figure illustrates a side view of the image sensor 104 according to an embodiment of the invention, being a cross sectional view of the semiconductor material that contains the photosites 108a and 108b. In this embodiment, each photosite has a photodiode with a respective p-n junction formed between a first semiconductor region 206 and a bulk region 208, with a depletion region delineated by the dotted line. The bulk region 208 may be a continuous substrate of an integrated circuit (IC) die in which all of the photosites of the array are formed, or it may be a number of wells (tubs) of the

same conductivity type formed in a substrate of the opposite conductivity type in the IC die. Although shown as p-type, the bulk region may alternatively be n-type, depending upon the type of photodetector used in the photosite. More generally, the bulk region 208 may be any semiconductor region on the surface of which the photosites of the sensor array responsible for capturing the scene are disposed, where a photosensitive portion of each photosite may be formed inside the bulk region.

The photons of the incident light create photogenerated electron-hole pairs in the photosensitive regions of the sensor array. These may be created either inside or outside the depletion region of a photodiode. Once created, the electrons (indicated by the "-" sign) are collected by the depletion region of the photosite, while some of the holes (indicated by a "+") contribute to a bulk current in a conducting terminal which may be shorted to the bulk region 208. Each photosite 108 and the region between photosites in the image sensor 104 may contribute such holes to form the bulk current. The bulk current has a primary contribution from photogenerated holes, but may also have an additional contribution due to leakage currents. The amplitude of this bulk current is proportional to the amount of light reflected from the scene and incident upon the image sensor 104 during the exposure interval in which the scene is being captured.

The bulk region is coupled to a common supply node 214 via a relatively low impedance path through a current measurement circuit 204. In this embodiment of the invention, the supply node 214 is ground (zero volts). The current measurement circuit 204 is capable of sensing the bulk current as, for instance, a voltage referenced to ground, and produces a signal that represents the bulk current at its output. The output of the current measurement circuit 204 is coupled to a threshold detection circuit 212 which provides an output signal for controlling the illumination of the scene in response to the output of the current measurement circuit 204 indicating that a particular threshold level of bulk current has been reached.

Fig. 3 illustrates an alternative to the circuit of **Fig. 2**, where the threshold detect circuit 212 is configured to compare a first signal being a bulk voltage, nonetheless representative of the bulk current, to a predetermined threshold level, and in response, generate a signal to control the illumination. In this

embodiment, the bulk voltage is the voltage that is generated across a load (not shown) inside the threshold detect circuit 212 when the bulk current flows into the supply node 214.

Fig. 4 illustrates a schematic of a particular embodiment of the invention, including a particular version of the current measurement circuit 204 and the threshold detection circuit 212 that corresponds to the embodiment of **Fig. 2**. The current measurement circuit 204 in this embodiment includes a resistor 420 connected between the bulk region 208 and the supply node 214. A first switch 424 is provided to zero the output of the current measurement circuit 204, for the condition where no bulk current is to be sensed. The current measurement circuit 204 also includes an integrator represented here by a capacitor 428 that is coupled to integrate the voltage across the resistor 420 which is buffered by an amplifier 432. The output of the integrator takes the form of a ramp signal that has an amplitude proportional to the total energy incident on the image sensor from the scene under illumination. A second switch 434 is provided to zero the output of the integrator. This will be done at the start of the exposure interval in which the photosites are allowed to detect the incident light. The output of the integrator, in this embodiment being the voltage across the capacitor 428, is compared to a threshold signal VREF1 using a comparator 440. The output of the comparator 440 delivers the signal used to control illumination of the scene. In this particular embodiment, when the output of the integrator, during a given exposure interval, slightly exceeds the threshold signal VREF1, the output of the comparator 440 changes, thus acting as a trigger to quench, i.e. substantially lower the output of or shut off, the strobe which illuminates the scene being captured by the photosites 108a and 108b.

The circuit in **Fig. 4** may be modified to implement the alternative embodiment of **Fig. 3** in which illumination is controlled in response to a bulk voltage having reached a predetermined threshold level, without integrating the bulk voltage. In this embodiment, the input of the comparator 440 in the threshold detection circuit 212 is shorted to the bulk region 208 which is referenced to ground through some load (not shown).

In operation, the various embodiments of the invention described above are used in a method for controlling the illumination of a scene while capturing the scene electronically. This yields high quality pictures using a relatively low

cost solid state camera in which the dedicated photosensor circuit and associated optics used to meter the scene is eliminated. The method is now described in view of the image sensor 104 illustrated in **Fig. 1** and the particular embodiment of **Fig. 4**. The references to RESET and SELECT signals below in **Figs. 5 and 6** are to those in **Fig. 1** that are applied to control the photosites 108.

Fig. 5 illustrates an exemplary timing diagram of the reset, select and other control signals that are used to capture the scene and control the strobe according to an embodiment of the invention. While RESET is asserted, the voltage across the capacitor 428 is zero. The start of the exposure interval occurs when RESET is deasserted and the photosites are allowed to convert incident energy (reflected from the scene) into electrical signals. The strobe may have already been turned on, such that the light reflected from the scene and incident upon the image sensor includes light from this strobe. This in turn causes a bulk current to flow from the bulk region 208 (see **Fig. 4**). At approximately the same moment as RESET is deasserted, GROUND is deasserted which opens switch 424, such that the bulk current produced in the image sensor 104 can be detected by the current measurement circuit 204 as a voltage across the resistor 420. An INTEGRATED signal that represents the bulk current begins to ramp upwards at the output of the buffer 432 as the incident energy is received by the image sensor 104. The signal is compared to a predetermined threshold value VREF1 by the comparator 440. The threshold value represents the predetermined point at which the scene being captured is deemed properly illuminated, such that at this point, the strobe is to be lowered or shut off. This latter event is accomplished in response to the ILLUM CONTROL signal being asserted. In this embodiment, the exposure interval continues, in other words the photosites are allowed to continue to convert incident energy into electrical signals, beyond the point at which ILLUM CONTROL is asserted. This may involve the situation where there may be sources of light other than the strobe that are also illuminating the scene. Once the exposure interval is otherwise deemed complete, the SELECT signal is asserted and the photosite signals may be sampled. Thereafter, ILLUM CONTROL is deasserted to prepare the camera for the next exposure. Note that GROUND should be asserted at the same time as or before SELECT is asserted, so as to properly sample the photosite signals.

In some instances, the lowering or shutting off of the strobe during the exposure interval is immediately followed by the end of the exposure interval, as shown in the alternative timing diagram of **Fig. 6**. This is in contrast to the timing of **Fig. 5** in which the illumination is lowered or turned off at a much earlier time than the end of the exposure interval.

As another alternative, depending upon the ambient light conditions of the scene being captured, the illumination may be turned on or increased at some point later than the start of the exposure interval. The period of time the illumination is turned on or is kept at a relatively high level may be shifted to anywhere in the exposure interval or slightly before it, to yield images having the desired quality. This may be done based upon factors such as the nature of the particular scene being captured, the length of the exposure interval, the sensitivity of the image sensor photosites, and other imaging system parameters.

The above described embodiments of the invention featuring techniques for controlling illumination using the bulk current of an image sensor may be applied to a wide range of image sensor technologies. For instance, the sensor may be manufactured according to a metal oxide semiconductor (MOS) fabrication process in which each photosite has a photodiode coupled to reset circuitry and readout circuitry. The photodiode has one end coupled to the bulk region (in **Fig. 2**, this end is also shared by the bulk region 208) through a low impedance path, and another end to provide a voltage representing a portion the sensed scene (in **Fig. 2**, this end is n-type). Alternatively, the photosites of the image sensor may be charged coupled devices (CCDs). In either scenario, the bulk current that is measured is primarily the result of an exposure of the photosites and the rest of the image sensor to an image of the scene under illumination which is being captured at the same time by the image sensor.

Fig. 7 illustrates a block diagram of an imaging system 700, such as a solid state camera, which features certain embodiments of the invention for controlling illumination of a scene being captured. The system 700 has an image sensor 104 formed as a 2-dimensional array that provides photosite signals in analog form in response to light energy being incident upon the array. The incident light is guided by imaging optics 730 having an aperture 732 and a focusing lens 736, after being reflected from a scene (represented by the arrow). The incident light generates a bulk current (Ibulk) which flows into the current

measurement circuit 204. The current measurement circuit 204 and the threshold detect circuit 212 are part of control signal generation circuitry 704. This circuitry may also include column/row read control circuitry to generate the reset and select signals for the image sensor array. The reset and select signals are provided with the appropriate timing, such that all of the photosites in the sensor array can be properly sampled upon completion of the exposure interval, to form a electronic image. An exposure control circuit 706 is configured to instruct the threshold detect circuit 212 to quench the output of a strobe 740 prior to the end of an exposure interval in which the scene is captured by the sensor 104.

After the photosite signals have been sampled by bitline processing circuitry (not shown), they may be forwarded to an analog to digital converter 710 which digitizes the signals. These digitized signals are then processed according to known image and signal processing techniques, by digital processing block 714. The digital processing may include, for instance, color correction functions, scaling, and perhaps compression, to yield a digital image file or a sequence of digital image "frames" that constitute a video stream.

Once the digital images are created, they may be communicated to an image processing and/or viewing system, such as a stand-alone personal computer (not shown) or a printer, via a communication interface 724. The communication interface 724 may feature a computer peripheral bus interface, such as a high speed serial interface that is capable of transporting the digital images as a video stream. As an alternative, the digital images, and in particular still shots, may be placed in a removable storage device 728, such as a flash memory card, for subsequent transfer to the image processing and viewing equipment. The overall operation of the components in the imaging system 700 may be orchestrated by a system controller 722 that may feature a microcontroller or a processor that is executing firmware.

There are of course a wide range of alternatives for the architecture of the imaging system 700. For instance, the role of the system controller 722 may be expanded to include that of exposure control 706 and column/row read control 702, as well as the digital processing 714. The system controller 722 may be a sophisticated, logic state machine rather than a programmed processor. Furthermore, the system controller 722 may be configured to respond to

configuration commands received from outside of the system 700 via the communication interface 724, where the timing of the exposure intervals and the processing and transport of the digitized photosite signals and/or digital images are controlled by these configuration commands. As an example, the system 700 may be a digital camera that is tethered to a personal computer and is essentially controlled by software running on the personal computer.

To summarize, various embodiments of the invention that feature techniques for controlling the illumination of a scene, responsive to a signal that represents the bulk current from a solid state image sensor, have been described. Such embodiments contribute to lower manufacturing costs of the imaging system, by eliminating separate photosensor circuit and associated optics that are conventionally used to control the illumination of the scene.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A method comprising:

allowing light reflected from a scene to be incident upon an image sensor, the image sensor having a bulk region, the bulk region having disposed on a surface thereof a plurality of photosites of the image sensor;

providing a first signal representative of a bulk current from the bulk region; and

controlling illumination of the scene responsive to the first signal.

2. The method of Claim 1 further comprising:

integrating the first signal to provide a ramp signal, wherein the controlling includes comparing the ramp signal to a threshold signal.

3. The method of Claim 2 wherein the ramp signal has an amplitude representative of the exposure of the image sensor to the scene under illumination.

4. The method of Claim 1 wherein the first signal is a bulk voltage and the controlling includes comparing the bulk voltage to a threshold voltage.

5. The method of Claim 1 wherein the controlling includes quenching a strobe that illuminates the scene responsive to the first signal indicating that a predetermined illumination level has been reached.

6. The method of Claim 5 wherein the strobe is quenched prior to the end of an exposure interval in which the scene is captured by the image sensor.

7. An imaging apparatus comprising:

image sensor having a bulk region, the bulk region having disposed on a surface thereof a plurality of photosites of the image sensor;

current measurement circuit coupled to the bulk region and capable of sensing a bulk current from the bulk region; and

threshold detection circuit coupled to the current measurement circuit and capable of controlling illumination of the scene in response to the bulk current.

8. The apparatus of Claim 7 wherein the current measurement circuit includes an integrator coupled to integrate a first signal representing the bulk current, and wherein the threshold detection circuit includes a comparator that compares the output of the integrator to a threshold signal.

9. The apparatus of Claim 7 wherein the current measurement circuit provides a bulk voltage and the threshold detection circuit includes a comparator to compare the bulk voltage to a threshold voltage.

10. The apparatus of Claim 7 wherein the bulk current is primarily the result of an exposure of the image sensor to an image of the scene under illumination.

11. The apparatus of Claim 8 wherein the ramp signal has an amplitude proportional to the exposure of the image sensor, including the photosites, to the scene under illumination.

12. The apparatus of Claim 7 further comprising:

a strobe to illuminate the scene, and wherein the threshold detection circuit quenches the strobe responsive to the bulk current indicating that a predetermined level of bulk current has been reached.

13. The apparatus of Claim 12 further comprising:

exposure control circuit configured to instruct the threshold detection circuit to quench the strobe prior to the end of an exposure interval in which the scene is captured by the image sensor.

14. The apparatus of Claim 7 wherein the bulk region is a continuous substrate of an IC die that contains the image sensor.

15. The apparatus of Claim 7 wherein the bulk region is a plurality of wells of the same conductivity type formed in a substrate of an IC die and shorted to each other.

16. The apparatus of Claim 7 wherein each of the photosites includes a photodiode having one end coupled to the bulk region through a low impedance path and another end to provide a voltage representing a portion of the scene.

17. An apparatus comprising:

image sensor having a bulk region, the bulk region having disposed on a surface thereof a plurality of photosites of the image sensor;

means for providing a first signal representative of a bulk current from the bulk region; and

means responsive to the first signal for controlling illumination of the scene.

18. The apparatus of Claim 17 further comprising:

means for integrating the first signal to provide a ramp signal, wherein the controlling means includes means for comparing the ramp signal to a threshold signal.

19. The apparatus of Claim 17 wherein the controlling means includes means for comparing the first signal to a threshold signal.

20. The apparatus of Claim 17 wherein the bulk current results from the exposure of the image sensor, including the photosites, to an image of the scene under illumination.

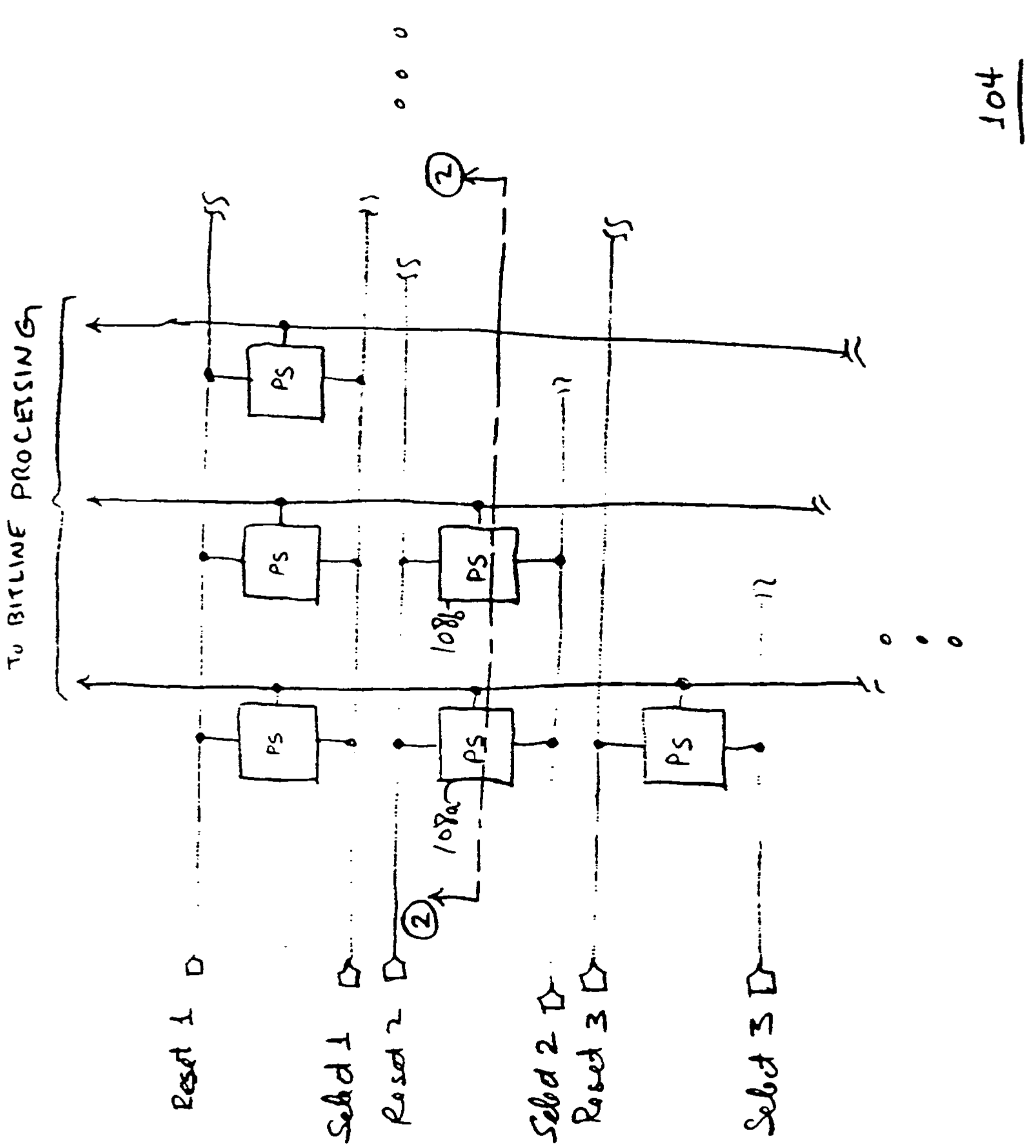

TO BITLINE PROCESSING
PS
PS
PS
PS
PS
PS
108a
108b
2
2
Reset 1
Select 1
Reset 2
Select 2
Reset 3
Select 3
104

Fig. 1

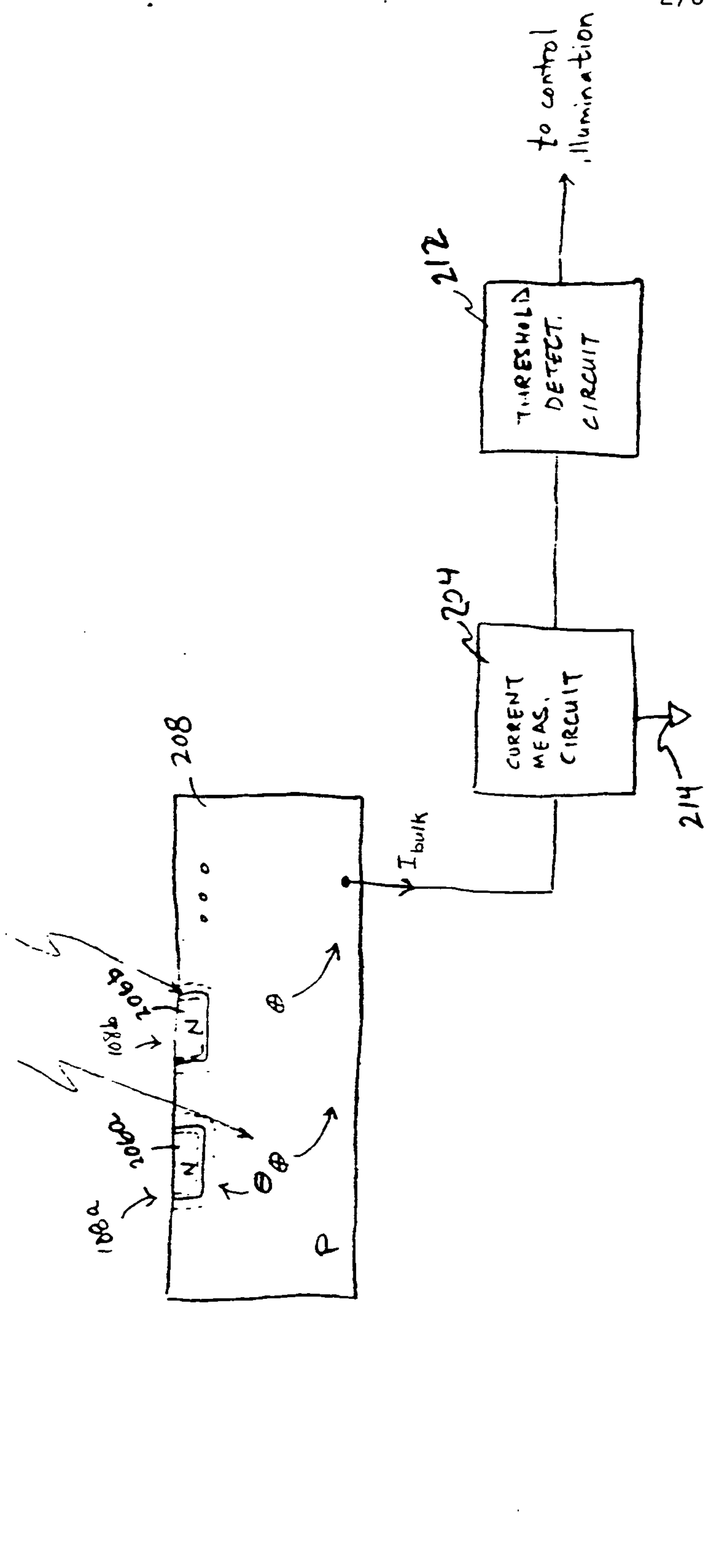
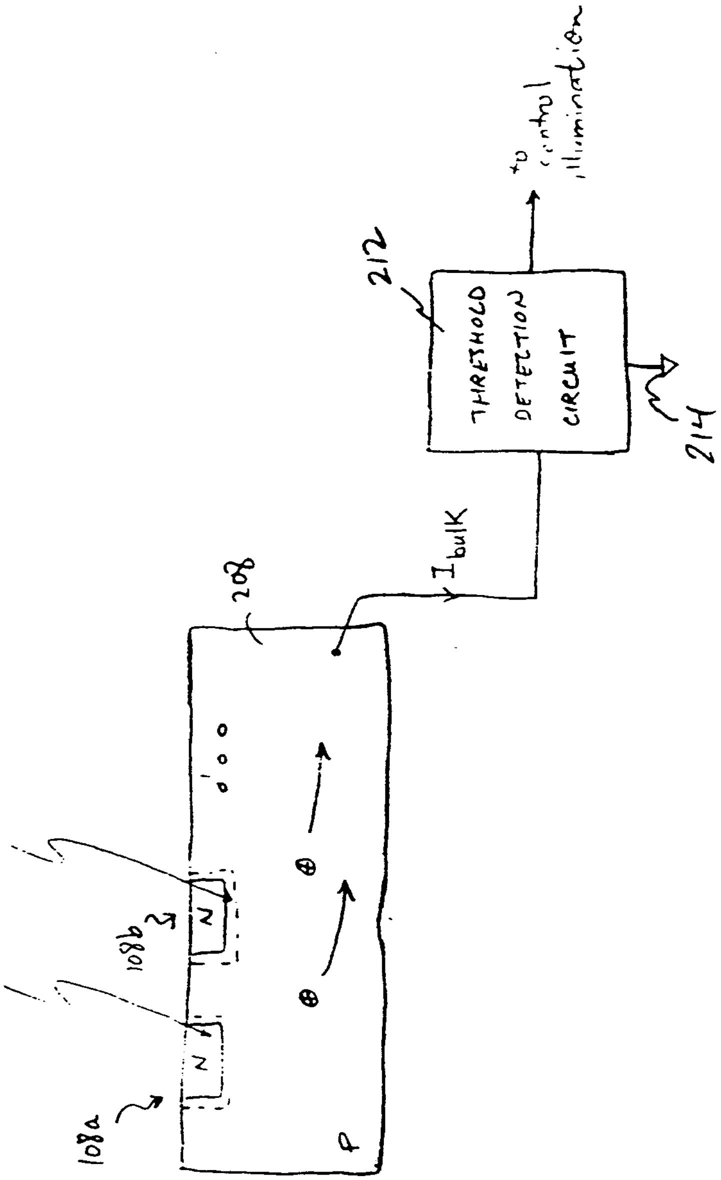

to control illumination
212
THRESHOLD DETECT. CIRCUIT
204
CURRENT MEAS. CIRCUIT
214
208
I_{bulk}
N
N
P
206a
206b
188a
188b

Fig. 2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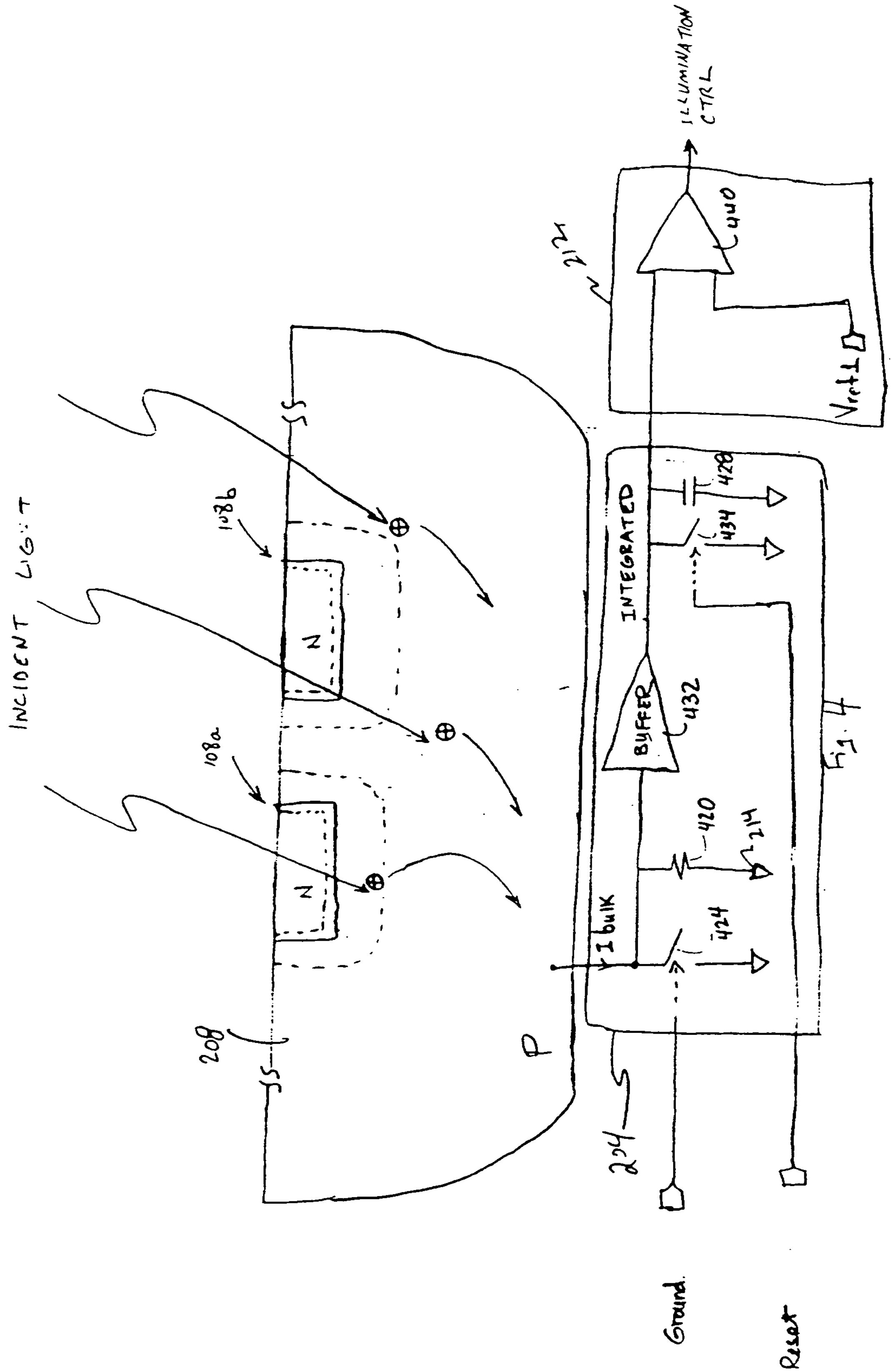
THRESHOLD DETECTION CIRCUIT
214
to control illumination
I_{bulk}
208
108a
108b
N
N
P

Fig. 3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440
Vref1
INCIDENT LIGHT
108b
108a
N
N
SS
208
P
INTEGRATED
428
434
BUFFER
432
420
214
Ibulk
424
224
Ground
Reset

Fig. 4

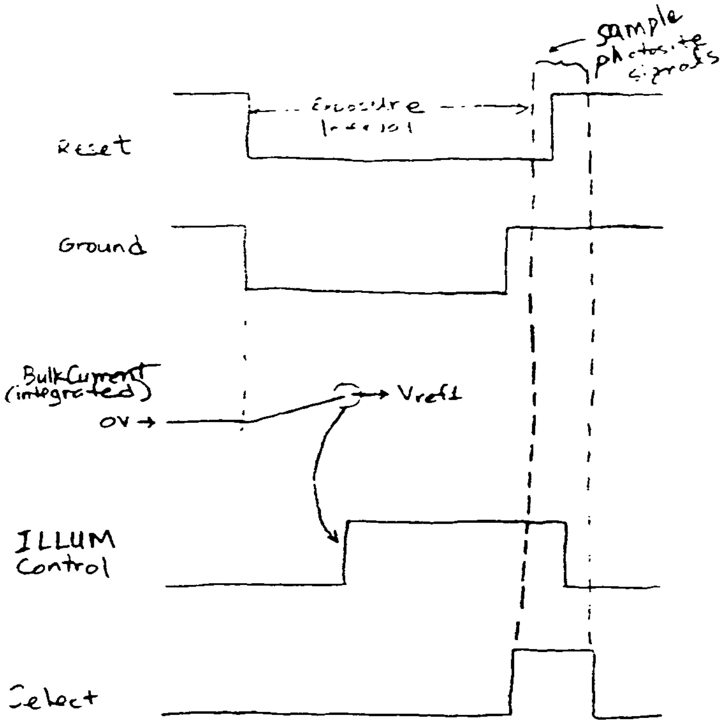
sample photosite signals
Exposure interval
Reset
Ground
Bulk Current (integrated)
0V →
→ Vref1
ILLUM Control
Select

Fig. 5

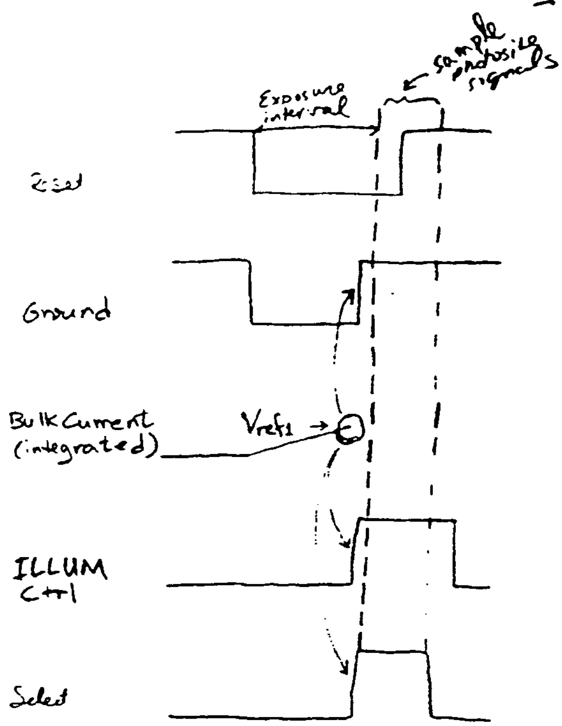
sample photosite signals
Exposure interval
Reset
Ground
Bulk Current (integrated)
Vref1 →
ILLUM Ctrl
Select

Fig. 6

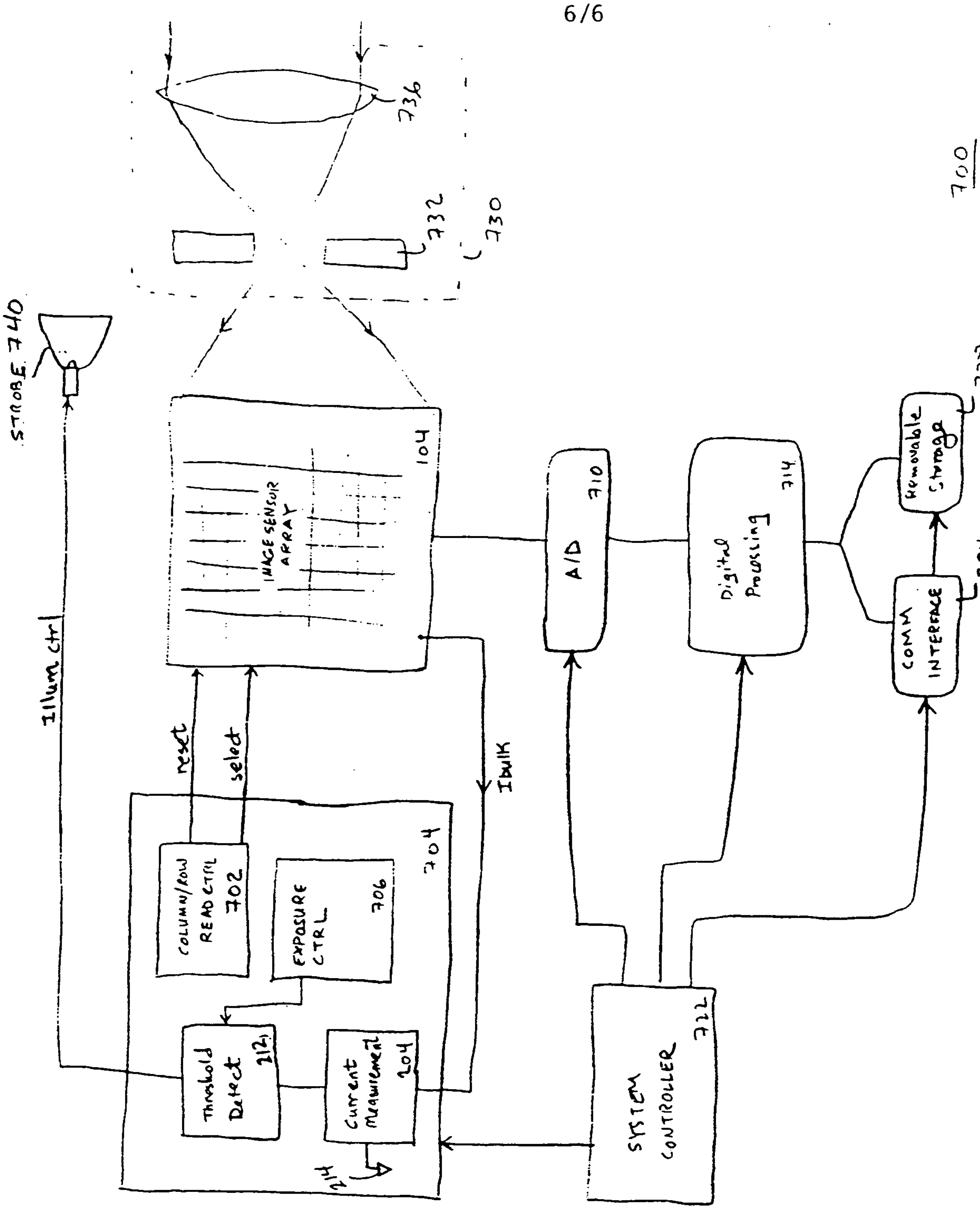

Fig. 7

042390.P4752

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/41090

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/235

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 809 076 A (TODAKA YOSHIHIRO ET AL) 28 February 1989 (1989-02-28) column 1, line 59 -column 2, line 12 column 10, line 42 - line 49 column 3, line 28 - line 46	1-5,7-12
A	US 4 338 514 A (BIXBY JAMES A) 6 July 1982 (1982-07-06) column 1, line 63 -column 2, line 31	1,7
A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 318 (E-1232), 13 July 1992 (1992-07-13) & JP 04 090688 A (CANON INC), 24 March 1992 (1992-03-24) abstract	1,7

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 March 2001	08/03/2001

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/41090

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 823 199 A (SAKAKIBARA KUNITERU ET AL) 18 April 1989 (1989-04-18) column 2, line 18 - line 28 -----	1,7

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/41090

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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